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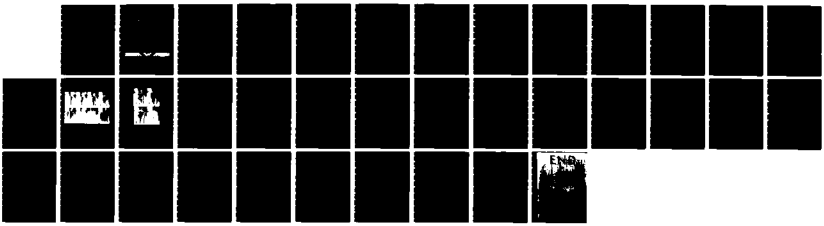

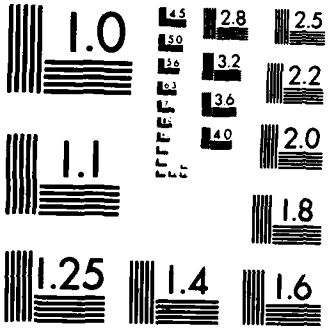

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REPORT NO. T 1/84

HEAT TRANSFER PROPERTIES OF COLD WEATHER LINER AND JACKET SYSTEMS BEFORE AND AFTER LAUNDERING

US ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

Natick, Massachusetts

OCTOBER 1983

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The heat transfer properties of eight prototype cold weather liner w/jacket systems were compared using the torso and arms sections of the sectional manikin. Evaluation of these liner w/jacket systems was done by measuring the effects on the insulation (clo) and evaporative heat transfer coefficient (i_m/clo) of replacing the standard liner w/jacket worn with a basic cold-weather ensemble with each of the experimental liner w/jacket combinations. These findings suggest that the basic differences existing among the liners

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are moderated by the addition of a jacket, which adds more or less insulation depending upon its fit in relation to the particular liner worn with it. Considering the insulation provided by all liner w/jacket combinations (laundered and unlaundered), the clo values for the torso-arms areas are within $\pm$ 7% of 4.5 clo; the evaporative heat transfer coefficient (i_m/clo) values are within $\pm$ 11% of a value of 0.09. These evaluations were done before and after three military launderings. These comparisons between the heat transfer properties of these prototype liner w/jacket systems before and after laundering indicate little differences between them when worn as components of a wet-cold ensemble.

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TECHNICAL REPORT
NO. T1/84

HEAT TRANSFER PROPERTIES OF COLD WEATHER LINER AND JACKET SYSTEMS BEFORE AND AFTER LAUNDERING

by

George F. Fonseca

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FOREWORD

This study is in support of a USANRDC project to develop a new jacket liner for cold weather clothing. During their lifetime such clothing components will have to undergo repeated washings. This could cause shrinkage, resulting in changes in their physical orientation causing a change in their insulation and moisture permeability properties. The Individual Protection Laboratory (IPL) requested that eight prototype liner w/jacket systems* be evaluated before and after three military launderings (cotton wash, tumble dry at 57°C). This evaluation consisted of measuring the changes in heat transfer properties (clo, i_m and i_m/clo) for the arm and torso coverings which were produced by replacing a standard liner w/jacket in a cold weather ensemble with each of the experimental liner w/jacket combinations. Measurements were made with a life-size electrically-heated sectional copper manikin.

*The eight prototype liners used in this study were furnished by Ms. Barbara Kirkwood, IPL (USANRDC).

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ABSTRACT

The heat transfer properties of eight prototype cold weather liner w/jacket systems were compared using the torso and arms sections of the sectional manikin. Evaluation of these liner w/jacket systems was done by measuring the effects on the insulation (clo) and evaporative heat transfer coefficient (i_m/clo) of replacing the standard liner w/jacket worn with a basic cold-weather ensemble with each of the experimental liner w/jacket combinations. These findings suggest that the basic differences existing among the liners are moderated by the addition of a jacket, which adds more or less insulation depending upon its fit in relation to the particular liner worn with it. Considering the insulation provided by all liner w/jacket combinations (laundered and unlaundered), the clo values for the torso-arms areas are within $\pm$ 7% of 4.5 clo; the evaporative heat transfer coefficient (i_m/clo) values are within $\pm$ 11% of a value of 0.09. These evaluations were done before and after three military launderings. These comparisons between the heat transfer properties of these prototype liner w/jacket systems before and after laundering indicate little differences between them when worn as components of a wet-cold ensemble.

1. INTRODUCTION

The effect of laundering on the dimensional stability of fabrics was being studied over thirty-five years ago (6). When precise insulation measurements on fabric systems using guarded flat plates became routine in the 1950's, one study found that repeated washings had no significant effect on the insulation properties of blankets (2). A recent study (1) also reached the same conclusion. These earlier studies were only concerned with the effect of laundering on the insulation properties of these materials. However, when activity ..gh a body secretes sweat which has to evaporate from the surface of the s. to provide body cooling. This moisture has to pass through the clothing to the ..ironment. Recent studies, therefore, to determine the heat transfer properti.. of clothing now assess not only its insulation properties but also the ability of clothing to transfer moisture from the surface of a body to the environment (4). Levell (3) investigated the effect of laundering and starching on both the insulation and the evaporative heat transfer coefficient for standard fatigues. Using an electrically heated copper manikin with a "skin" that could be wetted or left dry, these results showed that neither laundering nor starching had any effect on the insulation or moisture permeability index of this uniform. With the increased used of synthetic materials in fabricating clothing components for the military, there is continued interest in the effect on the insulation and vapor permeability of these clothing components with repeated washings. The present study is in support of a USANRDC project to develop a new jacket liner for cold weather clothing. The heat transfer properties of eight prototype liner w/jacket systems were determined over the areas of the sectional manikin covered by each of these liner w/jacket systems (i.e., the torso and arms areas). These liner w/jacket systems were evaluated before and after three military launderings (cotton wash, tumble dry at 57°C).

2. EXPERIMENTAL METHOD

The electrically heated sectional manikin consists of six sections: head, torso, arms, hands, legs and feet. The manikin was placed in a standing position in a large temperature and humidity controlled chamber (chamber dimensions: length 5.8 m, width 3.9 m and height 2.7 m); chamber environmental conditions were 15.5°C at 50% relative humidity. The heat loss from the manikin surface is determined from the electrical watts required to maintain the manikin surface temperature constant at an average of 35°C. For this study on jacket liners and jackets the torso and arms sections were considered the test sections and the remaining four sections (head, hands, legs and feet) were considered the guard sections. Manikin evaluations of the liner w/jacket systems were done by measuring the effect on the torso and arms insulation (clo), moisture permeability index (i_m) and evaporative heat transfer coefficient (i_m/clo) of replacing the standard liner and standard jacket worn with a basic cold-weather ensemble (Table I) with each of the experimental liner w/jacket combinations. These heat transfer properties over the torso and arms include the contribution of the wool undershirt and wool shirt in the standard cold-wet ensemble. Photographs of the eight experimental liners used in this study are shown in Figure 1. The quilted polyester liner was worn with the nylon-cotton jacket and with the Gore-Tex jacket. The four jackets worn as part of the liner w/jacket combinations are shown in Figure 2. The eight liners and four jackets evaluated on the manikin are given in Table II. As requested by the Individual Protection Laboratory (IPL), these manikin evaluations of the eight prototype liner w/jacket combinations were done before and after three military launderings (cotton wash, tumble dry at 57°C).

TABLE I

CLOTHING COMPONENTS WORN WITH EACH OF THE NINE

LINER AND JACKET COMBINATIONS

Undershirt mans: 50 cotton, 50 wool

Drawers mens: 50 cotton, 50 wool

Socks mens: wool cushion sole

Trousers mens: wool serge

Shirt mans: wool

Trousers men w/liner: cotton-nylon

Cap insulating helmet

Mitten inserts w/mitten shells

Boot insulated cold weather

Figure 1. Photographs of the eight liners used in this study; a. Quilted polyester; b. Unquilted Thinsulate; c. Sontique; c*. Sontique (camouflaged); d. Unquilted Thinsulate w/blue Gore-Tex laminate next to shirt; e. Unquilted Thinsulate w/blue Gore-Tex laminate away from shirt; f. Unquilted Thinsulate w/blue Gore-Tex laminate on both sides; s. Standard.

Figure 2. Photographs of the four jackets used in this study: C. Nylon-cotton experimental jacket #1 (camouflaged); E. Nylon-cotton experimental jacket #2; G. Gore-Tex jacket; S. Standard jacket.

TABLE II

LIST OF THE EIGHT LINERS AND FOUR JACKETS EVALUATED

LINERS

(a)	QUILTED POLYESTER
(b)	UNQUILTED THINSULATE
(c)	SONTIQUE
(c*)	SONTIQUE (CAMOUFLAGED)
(d)	UNQUILTED THINSULATE w/BLUE GORE-TEX LAMINATE NEXT TO SHIRT
(e)	UNQUILTED THINSULATE w/BLUE GORE-TEX AWAY FROM SHIRT
(f)	UNQUILTED THINSULATE w/BLUE GORE-TEX LAMINATE ON BOTH SIDES
(s)	STANDARD

JACKETS

C	NYLON-COTTON EXPERIMENTAL JACKET #1 (CAMOUFLAGED)
E	NYLON-COTTON EXPERIMENTAL JACKET #2
G	GORE-TEX JACKET
S	STANDARD JACKET

3. RESULTS

A. HEAT TRANSFER PROPERTIES OF LINER AND JACKET COMBINATIONS PRIOR TO LAUNDERING

Table III shows the contribution of each of the six sections (head, torso, arms, hands, legs and feet) to the total insulation (clo), moisture permeability index (i_m) and evaporative heat transfer coefficient (i_m/clo) for the unlaundered standard cold-wet ensemble. This cold-wet ensemble provides the most insulation and the largest impedance (lowest i_m/clo value) to evaporative heat transfer over the torso (except for the feet section). The insulation over the torso (4.9 clo) is about 70% greater than the total insulation (2.9 clo) for all six sections of the manikin. The evaporative heat transfer coefficient (i_m/clo) is 0.08 or 66% of the overall i_m/clo. Considering the area of the manikin covered by a liner w/jacket combination (torso-arms sections), the insulation is 4.2 clo or about 50% greater than the overall insulation and the evaporative heat transfer coefficient is 0.09 or about 75% of the total i_m/clo.

Table IV gives the heat transfer properties over the torso, arms and torso-arms sections prior to laundering for the eight prototype liner and jacket components substituted for the standard liner and standard jacket worn with a cold-wet ensemble. Considering the insulation provided by all liner w/jacket systems, the clo values for the torso-arms sections are within $\pm$ 5% of 4.4 clo. The standard liner and standard jacket provides 4.2 clo of insulation. The nylon-cotton field jacket combination (a) with the quilted polyester liner (4.3 clo) provides the lowest value of insulation and combinations (b) unquilted Thinsulate liner, (c) unquilted Sontique liner and (f) unquilted Thinsulate liner with blue Gore-Tex laminate on both sides provided the most insulation, 4.6 clo. The (c*) Sontique liner (camouflaged) worn with the nylon-cotton field jacket (camouflaged) shows the largest value of evaporative heat transfer coefficient (i_m/clo), 0.10. All liner w/jacket combinations are within $\pm$ 11% of an i_m/clo value of 0.09.

TABLE III

HEAT TRANSFER PROPERTIES OF THE STANDARD COLD-WET ENSEMBLE
WORN WITH UNLAUNDERED STANDARD LINER AND JACKET

MANIKIN SECTIONS	clo	i_m	i_m/clo
HEAD	1.5	0.46	0.31
TORSO	4.9	0.39	0.08
ARMS	3.3	0.40	0.12
HANDS	2.4	0.38	0.16
LEGS	2.7	0.38	0.14
FEET	2.5	0.08	0.03
TORSO-ARMS	4.2	0.38	0.09
TORSO-ARMS-LEGS	3.4	0.37	0.11
TOTAL	2.9	0.35	0.12

TABLE IV

HEAT TRANSFER PROPERTIES OF THE STANDARD COLD-WET ENSEMBLE WORN WITH UNLAUNDERED PROTOTYPE LINER AND JACKET COMPONENTS SUBSTITUTED FOR THE STANDARD UNLAUNDERED LINER AND JACKET COMPONENTS

JACKET/LINER COMPONENTS	TORSO			ARMS			TORSO-ARMS		
NYLON/COTTON FIELD JACKET WITH:	clo	i_m	i_m/clo	clo	i_m	i_m/clo	clo	i_m	i_m/clo
a. Quilted Polyester Liner	5.0	0.30	0.06	3.5	0.42	0.12	4.3	0.34	0.08
b. Unquilted Thinsulate Liner	5.3	0.37	0.07	3.7	0.41	0.11	4.6	0.41	0.09
c. Unquilted Sontique Liner	5.2	0.42	0.08	3.8	0.42	0.11	4.6	0.41	0.09
d. Unquilted Thinsulate Liner with blue Gore-tex Laminate next to shirt	5.3	0.37	0.07	3.6	0.36	0.10	4.5	0.36	0.08
e. Unquilted Thinsulate Liner with blue Gore-tex Laminate away from shirt	5.3	0.42	0.08	3.6	0.40	0.11	4.5	0.41	0.09
f. Unquilted Thinsulate Liner with blue Gore-tex Laminate on both sides	5.2	0.42	0.08	3.7	0.41	0.11	4.6	0.41	0.09
GORE-TEX FIELD JACKET WITH:									
a. Quilted Polyester Liner	5.2	0.31	0.06	3.4	0.41	0.12	4.4	0.35	0.08
NYLON-COTTON FIELD JACKET (CAMOUFLAGED) WITH:									
c*. Sontique (Camouflaged) Liner	5.3	0.42	0.08	3.4	0.48	0.14	4.4	0.44	0.10
STANDARD FIELD JACKET WITH:									
s. Standard Liner	4.9	0.39	0.08	3.3	0.40	0.12	4.2	0.38	0.09

TABLE V

HEAT TRANSFER PROPERTIES OF THE STANDARD COLD-WET ENSEMBLE WORN WITH LAUNDERED PROTOTYPE LINER AND JACKET COMPONENTS SUBSTITUTED FOR THE STANDARD UNLAUNDERED LINER AND JACKET COMPONENTS

JACKET/LINER COMPONENTS	TORSO			ARMS			TORSO-ARMS		
NYLON/COTTON FIELD JACKET WITH:	clo	i_m	i_m/clo	clo	i_m	i_m/clo	clo	i_m	i_m/clo
a. Quilted Polyester Liner	4.8	0.34	0.07	3.6	0.47	0.13	4.3	0.39	0.09
b. Unquilted Thinsulate Liner	4.9	0.34	0.07	3.7	0.48	0.13	4.4	0.40	0.09
c. Unquilted Sontique Liner	5.4	0.43	0.08	3.9	0.51	0.13	4.8	0.43	0.09
d. Unquilted Thinsulate Liner with blue Gore-tex Laminate next to shirt	5.2	0.36	0.07	3.6	0.47	0.13	4.5	0.41	0.09
e. Unquilted Thinsulate Liner with blue Gore-tex Laminate away from shirt	5.3	0.37	0.07	3.8	0.49	0.13	4.6	0.41	0.09
f. Unquilted Thinsulate Liner with blue Gore-tex Laminate on both sides	5.3	0.42	0.08	3.7	0.48	0.13	4.6	0.46	0.10
GORE-TEX FIELD JACKET WITH:									
a. Quilted Polyester Liner	4.9	0.29	0.06	3.5	0.42	0.12	4.3	0.34	0.08
NYLON-COTTON FIELD JACKET (CAMOUFLAGED) WITH:									
c*. Sontique (Camouflaged) Liner	5.3	0.41	0.08	3.2	0.43	0.13	4.4	0.43	0.10

B. HEAT TRANSFER PROPERTIES OF LINER AND JACKET COMBINATIONS AFTER LAUNDERING

Table V gives the heat transfer properties over the torso, arms and torso-arms after laundering for the prototype liners and jackets substituted for the standard liner and standard jacket. All values of insulation (clo) over the torso-arms sections are within $\pm$ 7% of an average clo value of 4.5 clo with the combinations having the quilted polyester liner (a) with the nylon-cotton field jacket or the Gore-Tex field jacket showing the lowest insulation value, 4.3 clo. The most insulation over the torso-arms sections is provided by the combination using the unquilted Sontique liner (c) and the nylon-cotton field jacket, 4.8 clo. The nylon-cotton field jacket worn with the unquilted Thinsulate liner with blue Gore-Tex laminate on both sides (f) or the (c*) unquilted Sontique (camouflaged) liner worn with the nylon-cotton field jacket (camouflaged) show the largest values of i_m/clo, 0.10. The quilted polyester liner (a) with the Gore-Tex jacket shows the lowest value, 0.08. All liner w/jacket combinations are within $\pm$ 11% of an i_m/clo value of 0.09. Figure 3 shows a graphic presentation of the insulation (clo) and evaporative heat transfer coefficient (i_m/clo) for all prototype liner w/jacket combinations before and after laundering. This Figure shows the small differences obtained between the corresponding values (clo and i_m/clo) for a liner w/jacket combination before and after laundering. The average of the insulation (clo) values over the torso and arms for all liner w/jacket combinations before laundering is within 0.1 clo of the average after laundering; 4.4 and 4.5 clo, respectively. Similarly, the average evaporative heat transfer coefficients (i_m/clo) before and after laundering are the same; 0.09. Corresponding values of insulation before and after laundering show little or only slight differences between them; five of these liner w/jacket combinations show no change in their evaporative heat transfer coefficient. Three show about a 10% increase after laundering, and none show a decrease after laundering.

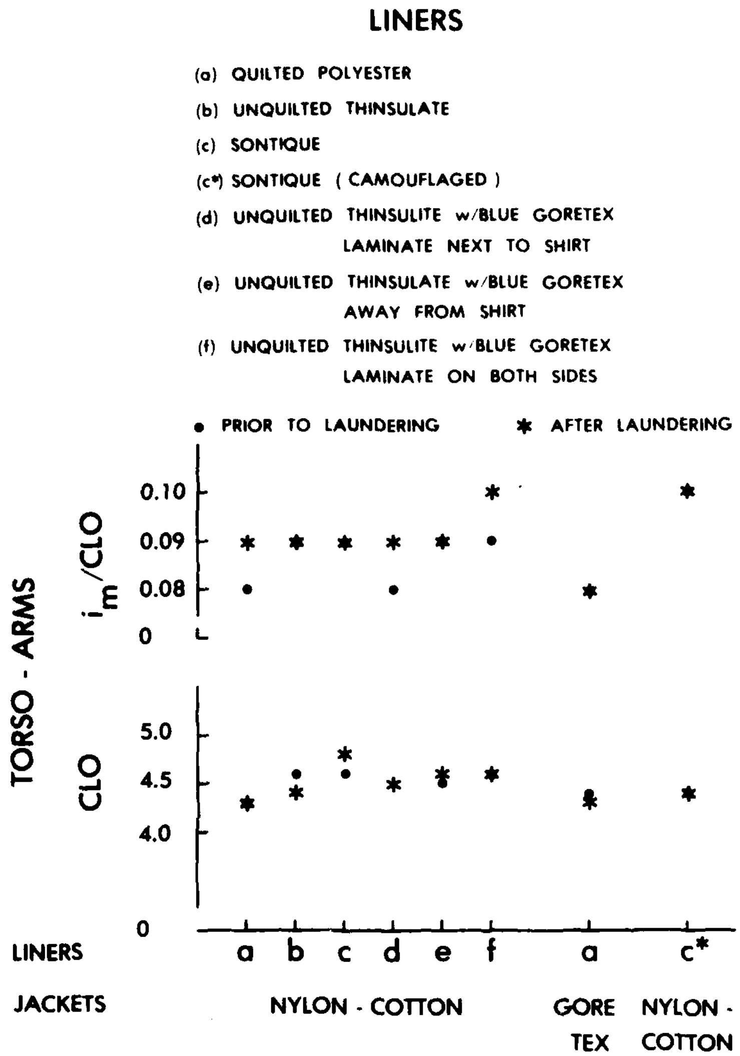

Figure 3. Graphic presentation of the torso-arms insulation (clo) and the evaporative heat transfer coefficient (i_m/clo) for all prototype liner w/jacket combinations prior to and after laundering.

4. DISCUSSION

A bulky, single-layer cold weather clothing system could provide insulation equivalent to a multiple-layer cold weather clothing ensemble. The difficulty with such one-piece garments is that there is very little adjustment possible to compensate for changes in activity or environmental conditions; the garment is either completely closed to provide maximum insulation for protection against a severe cold climate when activity is low, or completely open to permit body heat dissipation during periods of high activity. A multiple-layer clothing system for cold weather clothing permits individual clothing components to be added or removed, time permitting, to adjust for changes in activity or environmental conditions. However, the insulation values provided by the individual clothing components of a multiple-layer cold weather clothing system cannot be simply added together to obtain a total insulation value for the ensemble. If the clothing components fit so tightly on the body that one or more insulating layers are compressed by another layer of clothing or if the layers fit so loosely on the body that wind or body motion permits cold air to disturb the trapped warm air between and within the insulating layers, then the total insulation provided by a clothing ensemble will be less than if these components fit snugly on the body with a minimum of compression. Similarly, the resistance to evaporative heat transfer through a multiple-layer clothing system could be considerably different than the resistance calculated from the properties of the individual insulating layers (7). To take into account the interactions between the clothing components which are dependent upon the properties of drape and fit requires that the clothing be dressed on a life-sized model. Such a model is the heated copper manikin. This heated copper manikin permits a determination of both the insulation (clo) and evaporative heat transfer (i_m/clo) properties of a complete multi-layer clothing ensemble in the dressed mode. Any effect of compression

of the underlying insulating layers and the contribution of the air spaces between these layers is included in the evaluation of the heat transfer properties of a complete clothing ensemble. It is a relatively simple matter to demonstrate the effects of fit, drape and compressibility using the manikin; wind effects and the effects of water resistant treatments, among other factors, can be readily assessed, thus permitting a realistic evaluation of the protective merits of a particular ensemble. The only major shortcoming of the copper manikin is its rigid form, which prevents the effects of body motion on the clothing parameters from being measured directly. This situation will be rectified shortly, after a "walking" articulated manikin under construction becomes available for biophysical clothing assessments.

5. CONCLUSIONS

This comparison of the heat transfer properties of the eight prototype liner w/jacket systems before and after laundering indicates little differences between them when worn as components of a wet-cold ensemble. The findings suggest that the basic differences existing among the liners are moderated by the addition of a jacket which adds more or less insulation depending upon its fit in relation to the particular liner worn with it.

6. ACKNOWLEDGMENTS

The author thanks Mrs. Edna R. Safran for her substantial contribution to the administrative work connected with the publishing of this report and Clement A. Levell for the photographs shown in this report.

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8. APPENDIX

A. Insulation (clo) over the torso and arms as a function of the weight (kg) of the clothing components dressed over the torso and arms.

Since these liner w/jacket combinations are similar clothing components covering the torso and arms area of the sectional manikin, it is possible to compare the insulation provided by these liners and jackets as a function of their weight. Figure 4 gives the insulation (clo) over the torso and arms plotted against the weight (kg) of the clothing components dressed over the torso and arms. These plots of insulation as a function of weight include the contribution of the insulation provided by the external air layer. Wearing a wool undershirt, wool shirt and a liner over the torso provides an average value of about 2.1 clo per kg weight of clothing. The standard liner, because of its comparatively light weight, provides the most insulation per kilogram over the torso and arms; 2.6 clo/kg. The effect on the insulation per kilogram of clothing when a jacket is worn with a liner is to decrease the insulation per kilogram to about 1.3 clo/kg. Although wearing any one of the four jackets (without a liner) over the wool undershirt and wool shirt provides about 3.3 clo of insulation over the torso and arms, the addition of the Gore-Tex jacket provides 1.5 clo/kg compared with 1.2 clo/kg for either experimental jacket.

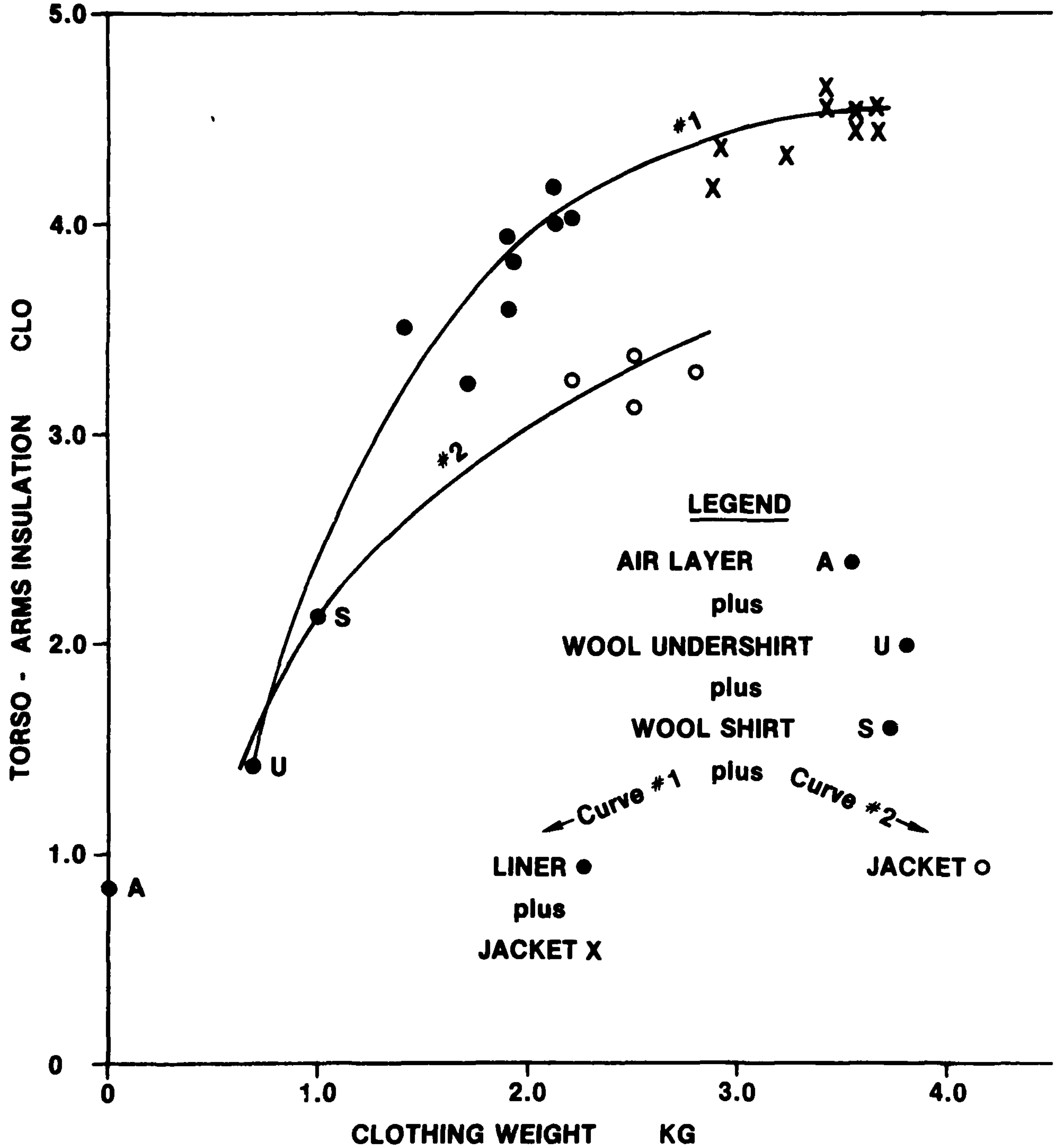

Figure 4. Insulation (clo) over the torso and arms plotted against the weight (kg) of the clothing components on the torso and arms:
Curve #1: wool undershirt plus wool shirt plus liner plus jacket
Curve #2: wool undershirt plus wool shirt plus jacket

B. Increase in insulation (clo) over the torso, arms and torso-arms areas when clothing components are added.

Insulation Over The Arms

The insulation over any manikin section depends upon the thickness of the dead air layers which are trapped within and between the clothing components surrounding a section. Provided that a clothing component is not compressed by another clothing component, the thicker the layer of clothing, the greater the thickness of the trapped air layer and the better the insulation. Figure 5 shows the increases in insulation (clo) over the arms (part A), the torso (part B) and the torso and arms (part C), as clothing components are dressed on the manikin. In the low air flow conditions (about 0.1 m/s) existing in the sectional manikin chamber, the air layer surrounding the arms provides about 0.7 clo of insulation before any clothing is dressed on the manikin. Adding a wool undershirt increases the insulation to 1.2 clo and a wool shirt adds another 0.6 clo for a total insulating value of 1.8 clo before any liner w/jacket system is dressed on the manikin. Adding a liner increases the insulation over the arms to between 2.8 clo for the quilted polyester liner (a) and 3.6 clo for the unquilted Sontique liner (c). Adding a jacket over a liner increases the insulation over the arms to 3.3 clo (from 2.8 clo) for the standard liner w/standard jacket system and to 3.8 clo (from 3.6 clo) for the unquilted Sontique liner (c) with the nylon-cotton field jacket (E). The spread in the insulation values over the arms for these liner w/jacket systems is 0.5 clo compared with 0.8 clo when only the liners are worn. This compression in the spread of clo values when a complete liner w/jacket system is worn compared with the spread in clo values when only a liner is worn apparently results from the fit of a jacket causing more or less compression of the dead air layers within and between these clothing components.

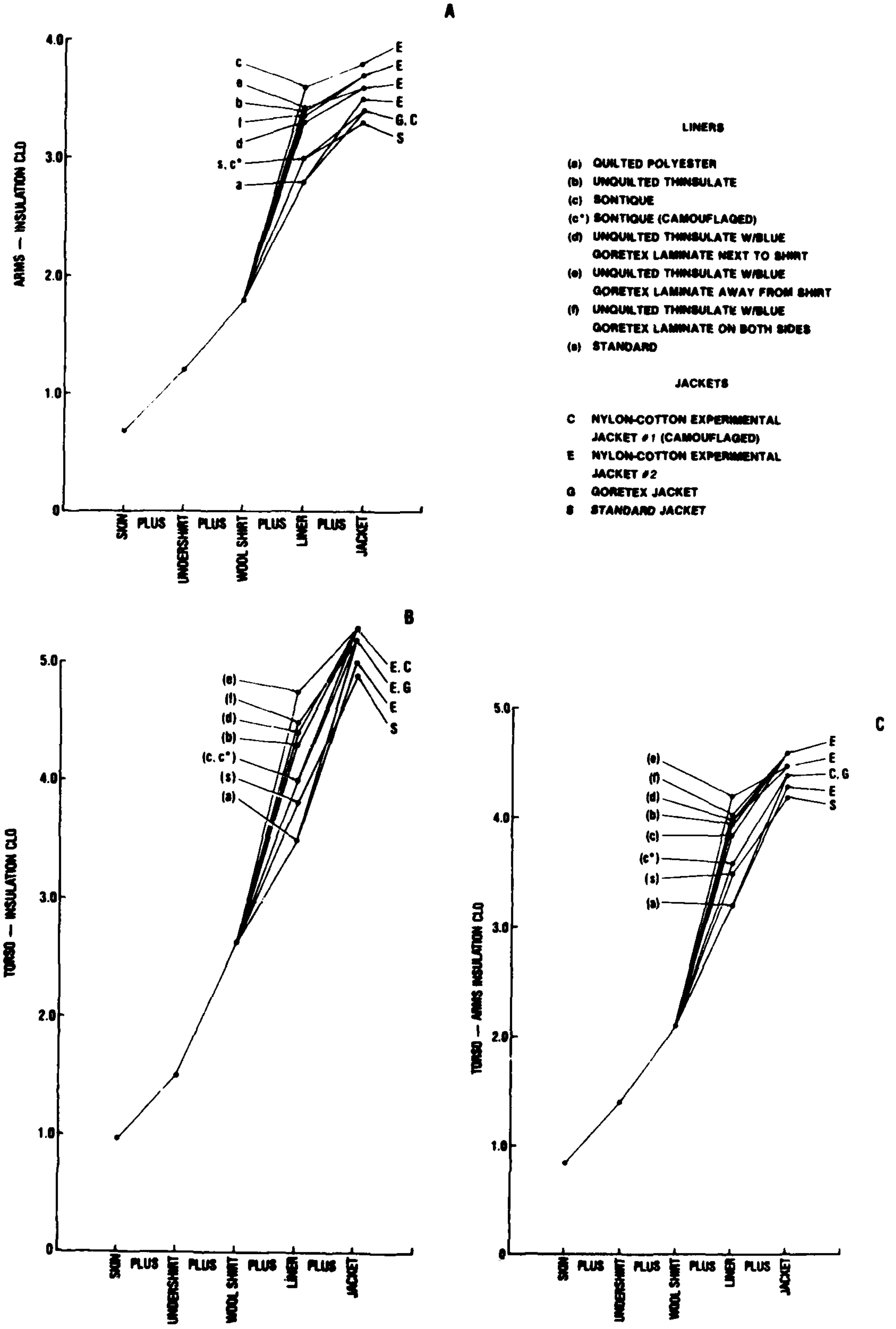

Figure 5. Insulation (clo) plotted against the clothing components on the: A. Arms; B. Torso; and C. Torso and Arms

Insulation Over The Torso

The increases in insulation over the torso as clothing components are added is shown in Part B of Figure 5. The air layer surrounding the torso provides about 0.9 clo of insulation before any torso clothing is dressed on the manikin. Adding a wool undershirt increases the insulation to 1.5 clo and a wool shirt adds another 0.9 clo for a total insulating value of 2.4 clo before any liner w/jacket system is dressed on the manikin. Adding a liner increases the insulation over the torso to a range from 3.5 clo for the quilted polyester liner (a) and 4.8 clo for the unquilted Thinsulate liner with blue Gore-Tex laminate away from the shirt (e). Adding a jacket over a liner increases the torso insulation to between 4.9 clo for the standard liner (s) w/standard jacket system and 5.3 clo for the unquilted Thinsulate liner with blue Gore-Tex laminate away from the shirt (e). The spread in the insulation values over the torso with the jackets in place is 0.4 clo compared with 1.3 clo when the jackets are not worn. Considering average clo values based on all nine liner w/jacket systems shows that the insulation over the arms is 31% less than the insulation over the torso.

Insulation Over The Torso-Arms

The insulation value over the torso contributes about two-thirds to the total insulation value over the torso-arms sections; the insulation value over the arms contributes the remaining one third. The increases in these insulating values as clothing components are added are given in Part C of Figure 5. The air layer surrounding the torso-arms sections provides about 0.8 clo of insulation. Adding a wool undershirt increases the insulation to 1.4 clo and a wool shirt adds another 0.7 clo for a total insulating value of 2.1 clo. Adding a liner increases the insulation over the torso-arms to between 3.2 clo for the quilted polyester liner (a) and 4.2 clo for the unquilted Thinsulate liner with the blue Gore-Tex laminate away from the shirt (e). Adding a jacket over a liner increases the

insulation over the torso-arms to 4.2 clo (from 3.5 clo) for the standard liner (s) w/standard jacket system and to 4.6 clo (from 3.9 clo) for the unquilted Thinsulate liner (b), unquilted Sontique liner (c) and unquilted Thinsulate liner with blue Gore-Tex laminate on both sides (f); all worn with the nylon/cotton field jacket. The spread in the insulation values over the torso-arms for these liner w/jacket systems is 0.4 clo compared with 1.0 clo when the jackets are not worn. This decrease in the spread of the insulating values over both the torso and arms sections when the jackets are worn suggests that the basic differences existing among the liners, i.e., fabrication, thickness, density, tightness or looseness of fit, etc., is moderated by the addition of a jacket. Hence, the net contribution of the jacket depends upon its fit in relation to the particular liner worn with it.

C. Decrease in the evaporative heat transfer coefficient (i_m/clo) for the torso, arms and torso-arms areas when clothing components are added

Evaporative Heat Transfer Over The Arms

The evaporative heat transfer coefficient for any manikin section depends upon the porosity and thickness of the clothing components covering that section. The greater the air porosity of a clothing system, the greater the paths available for water vapor to pass from the skin through the clothing to the environment. Mecheels and Heinz-Umbach (5) predict the evaporative resistance from measurements of fabric properties and dry heat loss measurements. Whelan et al. obtained a relationship between porosity, thickness, etc. and the resistance to evaporative heat transfer (7). Multiple layer clothing systems such as a liner w/jacket system allow evaporative heat transfer which can be different than that expected from the individual resistance values for the separate layers since the paths through such a clothing system are dependent upon the influence of the adjacent layers, e.g., compression of the insulating

layer by the jacket. Figure 6 shows the decreases in the evaporative heat transfer coefficient (i_m/clo) over the arms (part A), the torso (part B) and the torso and arms (part C), as clothing components are dressed on the manikin. The air layer surrounding the arms has an i_m/clo value of 0.53 before any clothing is dressed on the manikin. Adding an undershirt decreases the i_m/clo value to 0.37, and a wool shirt to 0.23 before any liner w/jacket system is dressed on the manikin. Adding a liner decreases the i_m/clo values for the arms to a range from 0.15 for the Sontique liner (c) to 0.12 for the unquilted Thinsulate w/blue Gore-Tex laminate on both sides (f). Adding a jacket over the liner further decreases the range of i_m/clo values to between 0.14 for the Sontique (camouflage) liner (c) w/nylon-cotton field jacket (camouflage) and 0.10 for the unquilted Thinsulate liner with blue Gore-Tex laminate next to the shirt (d) w/nylon-cotton field jacket. The spread in i_m/clo values over the arms for these liner w/jacket systems is 0.04 compared with 0.03 when the jackets are not worn; adding a jacket had little effect on the spread of i_m/clo values over the arms.

Evaporative Heat Transfer Over The Torso

The air layer surrounding the torso has an i_m/clo of 0.36 before any torso clothing is dressed on the manikin. Adding a wool undershirt decreases the i_m/clo value to 0.24 and the addition of a wool shirt further decreases i_m/clo to 0.16. Adding a liner decreases the torso i_m/clo range to between 0.08 for the Sontique liner (c) and Sontique liner (camouflaged) (c*) and 0.11 for the unquilted Thinsulate liner (b) and the standard liner (s). Adding a jacket over the liner decreases the evaporative coefficient for the torso to a range from 0.08 for the unquilted Sontique (c), unquilted Thinsulate with the blue Gore-Tex laminate away from shirt (e), and unquilted Thinsulate with blue Gore-Tex laminate on both sides (f) (all these liners worn with the nylon-cotton field jacket) and 0.06 for the quilted polyester liner (a) worn with the nylon-cotton field jacket or Gore-Tex field jacket, the Sontique liner (camouflaged) (c*) worn with the nylon-

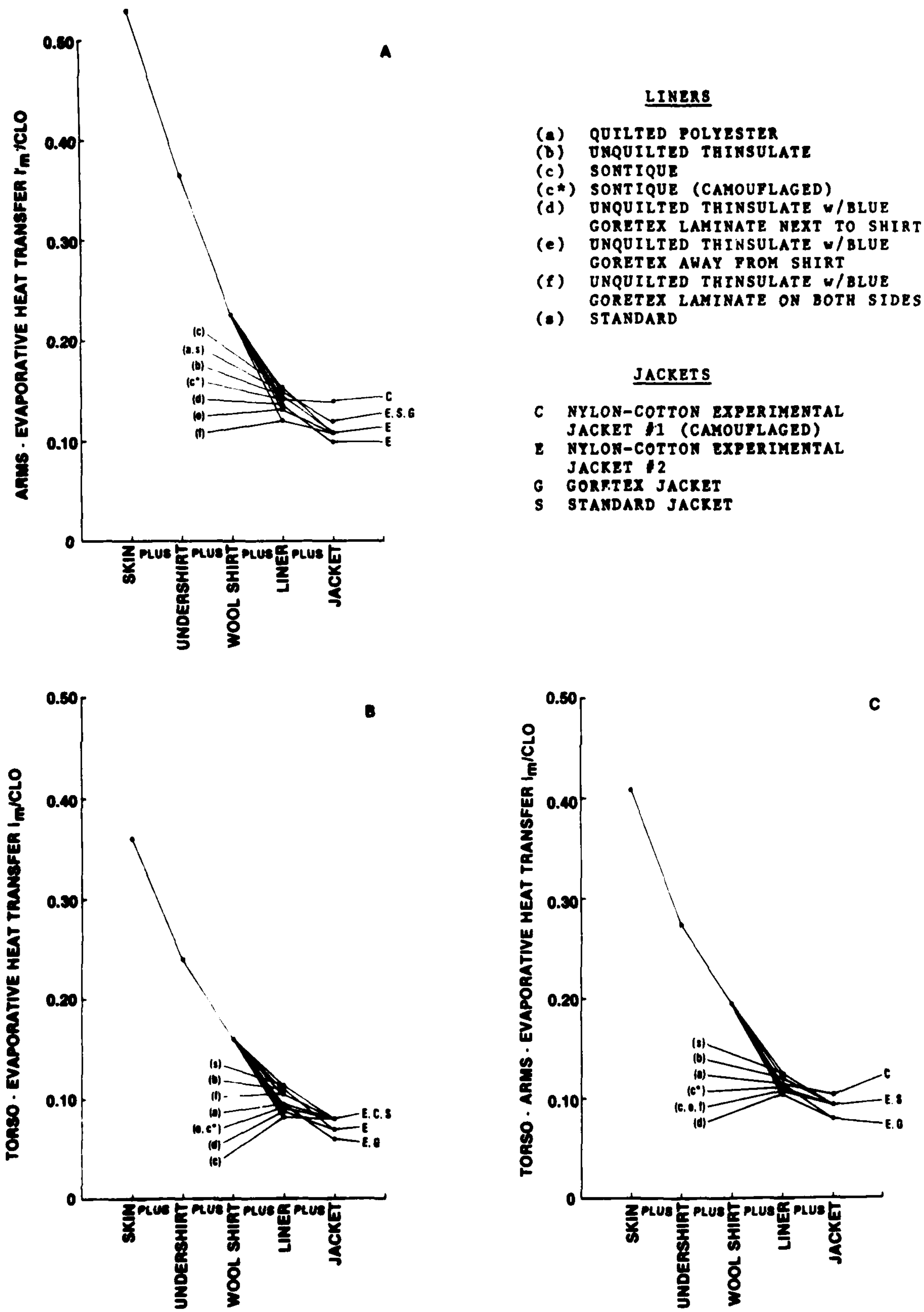

Figure 6. Evaporative heat transfer coefficient (i_m/clo) plotted against the clothing components on the: A. Arms, B. Torso, and C. Torso and Arms

cotton field jacket (camouflaged), and the standard liner (s) worn with the standard field jacket. The spread in values when a liner is worn alone is 0.03 and when worn with a jacket is also 0.03. Considering average i_m/clo values based on all nine liner w/jacket systems shows that the evaporative heat transfer coefficient (i_m/clo) is 59% greater for the arms than for the torso.

Evaporative Heat Transfer Over The Torso-Arms

Figure 6 (part C) shows the combined effect on i_m/clo for the torso-arms areas of adding clothing components. The i_m/clo value for this area is 0.41 without clothing. Adding a wool undershirt decreases i_m/clo to 0.28 and the addition of a wool shirt further decreases it to 0.20. Adding a liner decreases these values to the range from 0.09 for the Sontique liner (camouflaged), (c*) and 0.12 for the unquilted Thinsulate liner (b) and the standard liner (s). Adding a jacket over the liner further decreases the i_m/clo range for the torso-arms areas to between 0.10 for the Sontique (camouflaged) liner (c*) plus nylon-cotton field jacket (camouflaged) and 0.08 for the quilted polyester liner (a) or unquilted Thinsulate liner with blue Gore-Tex laminate next to the shirt (d), both worn with the nylon-cotton field jacket, and the quilted polyester liner (a) worn with the Gore-Tex field jacket. The spread in these values when a liner is worn with or without a jacket is about 0.02.

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